

DATE OF MAILING: June 30, 2000

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Title: **SPOT MARKET-BASED INVENTORY PLANNING**

Citizenship: United States

Citizenship: United States

Citizenship: Italian

Citizenship: United States

SPOT MARKET-BASED INVENTORY PLANNING

CROSS-REFERENCE TO RELATED APPLICATIONS

Sub 21
This application is related to U.S. Application Serial No. ___, filed on even date herewith, by Steve Kakouros et al., and entitled "Spot Market-Based Inventory Planning Tools," and to U.S. Application Serial No. ___, filed on even date herewith, by Steve Kakouros et al., and entitled "Spot Market-Based Inventory Planning Services," both of which are incorporated herein by reference.

COPYRIGHT

A portion of the disclosure of this patent document contains material that is subject to copyright protection. The copyright owner has no objection to the facsimile reproduction by anyone of the patent disclosure, as it appears in the Patent and Trademark Office patent files or records, but otherwise reserves all copyright rights whatsoever.

TECHNICAL FIELD

This invention relates to systems and methods for planning inventories when supply is available from a spot market.

BACKGROUND

Asset managers of large manufacturing enterprises, for example, computer manufacturers, electronics manufacturers and auto manufacturers, must determine the inventory levels of components and finished products that are needed to meet specified end customer service levels (i.e., the fraction of customer orders that should be received by the requested delivery dates). For such manufacturing enterprises, the delivery of a finished product to an end customer typically involves a complex network of suppliers, fabrication sites, assembly locations, distribution centers and customer locations through which components and products flow. This network may be modeled as a supply chain that includes all significant entities participating in the transformation of raw materials or basic components into the finished products, which ultimately are delivered to the end customer.

Each of the steps in a supply chain involves some uncertainty. For example, for a variety of reasons (e.g., changes in product life cycles, seasonal variations in demand, and changing economic conditions), future end customer demand is uncertain. In addition, the times at which ordered raw materials and components will be received from suppliers is uncertain. To handle such uncertainty, many different statistical models have been proposed to determine the appropriate inventory levels (i.e., safety stock) to hold at each level of a supply chain to meet target service level requirements. Conventionally, safety stock levels may be estimated based upon the average lead time, the variance in the lead time, the average demand rate, and the variance in the demand rate (see, e.g., EDWARD A. SILVER & REIN PETERSON, DECISION SYSTEMS FOR INVENTORY MANAGEMENT AND PRODUCTION PLANNING (1985)). Various elaborations on this conventional inventory planning model have been proposed. For example, U.S. Patent No. 5,946,662 describes a method of optimizing inventories that enables asset managers to assess the tradeoff between service levels and the investment in inventories needed to support those service levels. U.S. Patent No. 5,819,232 describes an inventory planning method that incorporates customer order lead time information into the inventory level determination process. Still other inventory planning strategies have been proposed.

SUMMARY

Prior inventory planning schemes have focused on traditional supplier markets, which are characterized by relatively certain information about future prices but relatively uncertain information about future delivery times. The invention provides additional flexibility by accommodating supply availability from spot markets, which are characterized by relatively uncertain price information but relatively certain delivery information. By incorporating spot market supply information into an inventory planning model, the invention enables asset managers to take advantage of spot market supplies to reduce inventory levels and lower overall product supply costs relative to business models that rely solely on non-spot market supplies.

In one aspect, the invention features an inventory planning scheme in which a safety stock level is planned to cover uncertainty in demand over an exposure period with a desired service level based at least in part upon product availability from a spot market.

5 Embodiments of the invention may include one or more of the following features.

 A maximum safety stock level of the product to cover uncertainty in demand over the exposure period with the desired service level may be estimated based upon product availability from a non-spot market supply. An optimal safety stock level
10 may be estimated by reducing the maximum safety stock level based upon product availability from a spot market supply.

 The maximum safety stock level estimation preferably is based in part upon one or more of the following parameters: an estimation of lead time and lead time uncertainty for obtaining the product from the non-spot market supply; an estimation
15 of product demand and demand uncertainty for the product; and the review period between replenishment decisions.

 The optimal safety stock level estimation may be based in part upon a cost of obtaining the product from the spot market.

 The maximum safety stock level may be reduced based upon an estimation of
20 a total cost of covering the maximum safety stock level with a combination of product received from the spot market and product received from the non-spot market supply. The total cost may be estimated based in part upon an estimation of the expected amount of spot market product needed to cover uncertainty in demand over the exposure period with the desired service level for a given amount of non-
25 spot market product. The total cost also may be estimated based in part upon a cost of obtaining the product from the spot market and a cost of obtaining the product from the non-spot market supply.

 The optimal safety stock level preferably is estimated by minimizing the estimated total cost. The optimal safety stock level preferably corresponds to a safety
30 stock level that minimizes the estimated total cost. The optimal safety stock level

may be estimated based at least in part upon a stochastic simulation of one or more random variables.

The optimal safety stock level preferably is ordered from the non-spot market supply. A product level needed to meet actual demand above the optimal safety
5 stock level and within the desired service level preferably is ordered from the spot market supply.

Product may be ordered from the spot market by navigating a web site. In addition, the safety stock level may be planned by navigating a web site providing information relating to use of the spot market to plan an inventory level. The safety
10 stock level may be planned by providing information to an inventory planning engine that is accessible through the web site, including information relating to product demand and information relating to non-spot market lead time.

Enterprise resource planning also may be performed based upon the planned safety stock level.

15 Among the advantages of the invention are the following.

The invention provides an inventory planning scheme that enables an asset manager to cover uncertainty in future end customer demand with a safety stock level that is less than the safety stock level required to cover expected demand with a desired service level when supply is available only from non-spot market sources. In
20 this way, an asset manager may trade some certainty in product price for a greater certainty in product delivery times to reduce overall product costs by reducing the level of safety stock kept on hand. In particular, per unit prices of products supplied by spot market sources may be higher than the prices of comparable products and components supplied by non-spot market sources. However, depending upon
25 market conditions, overall supply chain costs may be lowered by reducing safety stock levels (and, consequently, lowering total safety stock costs), and supplying from spot market sources the fraction of unmet actual demand needed to reach target service levels.

Other features and advantages of the invention will become apparent from the
30 following description, including the drawings and the claims.

DESCRIPTION OF DRAWINGS

FIG. 1 is a block diagram of a distribution network that includes a non-spot market supply of products and a spot market supply of products.

FIG. 2 is a probability density plot of end customer exposure period demand
5 for a product.

FIGS. 3A and 3B are respective probability density plots of delivery lead time and product price for a non-spot market supply.

FIGS. 4A and 4B are respective probability density plots of delivery lead time and product price for a spot market supply.

10 FIG. 5 is a graph of product cost plotted as a function of the quantity of product received from a spot market supply in a graphical representation of an inventory planning process.

FIG. 6 is a flow diagram of an inventory planning cost minimization process.

FIG. 7 is a flow diagram of a basic inventory planning simulation process.

15 FIG. 8 is a block diagram of an enterprise resource planning system.

FIG. 9 is a flow diagram of an inventory planning process.

FIG. 10 is a block diagram of a computer network.

FIG. 11 is a block diagram of a server computer coupled to a plurality of remote computers.

20 FIG. 12 is a flow diagram of a method of providing inventory planning services.

FIG. 13 is a diagrammatic view of a graphical user interface providing information relating to use of a spot market to plan an inventory level.

DETAILED DESCRIPTION

25 I. DISTRIBUTION SYSTEM WITH A SPOT MARKET SUPPLY

Referring to FIG. 1, in one embodiment, a simplified distribution system 10 includes a network of end customers 12, suppliers 14, and a warehouse 16 that contains a product inventory 18. End customers 12 may include purchasers of branded retail products, purchasers of second label retail products, and direct sales
30 purchasers. In operation, end customer demand 20 drives orders 22, which are

generally is not needed for products supplied by spot market sources. Although spot market prices may fluctuate with changing market conditions, an asset manager is assured of obtaining from the spot market products needed to cover unmet actual demand at some (although uncertain and potentially high) price. This feature of spot market sources enables asset managers to reduce safety stock levels below the levels needed to cover service level requirements.

II. SPOT MARKET-BASED INVENTORY PLANNING TOOLS

As shown in FIG. 5, in one inventory planning process, it is assumed that the total amount of safety stock needed to cover the variability in end customer demand over the exposure period with a specified service level is represented by q_{MAX} . This level of safety stock may be met by a combination of a reduced safety stock level (q_{SAFETY}) that is kept on hand and supplied by non-spot market sources, and products supplied in real time by spot market sources (q_{SPOT}) to meet actual unmet demand that falls within target service level requirements ($q_{MAX} = q_{SAFETY} + q_{SPOT}$). The total non-spot market product cost ($C_{SAFETY}(q_{SPOT})$) decreases linearly with the amount of product supplied by non-spot market sources (q_{SPOT}). At the same time, the total spot market product cost ($C_{SPOT}(q_{SPOT})$) increases with the amount of product supplied by spot market sources (q_{SPOT}). In this model, the total spot market product cost is assumed to increase nonlinearly as a function of spot market quantity; however, in other models, the total spot market cost may increase linearly with spot market quantity or may vary with spot market quantity in ways selected to reflect actual conditions of the customer demand and the spot market. As shown, the total product cost ($C_{TOTAL}(q_{SPOT}) = C_{SAFETY}(q_{SPOT}) + C_{SPOT}(q_{SPOT})$) has a characteristic U shape, and is minimized when the maximum safety stock level (q_{MAX}) is reduced by the optimal quantity ($q_{SPOT, OPTIMAL}$) of product to be supplied by spot market sources. Depending upon actual demand and market conditions, the overall reduction in total product cost (ΔC) may be quite substantial.

Referring to FIG. 6, in one inventory planning process, the optimal safety stock level ($q_{SAFETY, OPTIMAL}$) that minimizes the total product cost may be estimated as follows. Initially, the maximum safety stock level (q_{MAX}) is estimated (step 40). The maximum safety stock level may be estimated by conventional inventory planning

techniques that assume supply availability solely from non-spot market sources. For example, the maximum safety stock level may be estimated by the product of a safety stock factor and the standard deviation of demand over the exposure period. In one embodiment, the maximum safety stock level (q_{MAX}) is estimated by the following equation:

$$q_{MAX} = \Phi^{-1}(\alpha) \times [\mu_D^2 \cdot \sigma_L^2 + (\mu_L + R) \cdot \sigma_D^2]^{1/2} \quad (1)$$

Where $\Phi^{-1}(z)$ is the standard normal inverse function, α is the service level specified as the probability of meeting all demand in the review period, μ_D is the estimated mean demand, σ_L is the estimated lead time standard deviation, μ_L is the estimated mean lead time, σ_D is the estimated demand standard deviation, and R is the review period. In equation (1), the factor $(\mu_L + R)$ corresponds to the exposure period. Other embodiments may estimate the maximum safety stock level in different ways.

The safety stock level is reduced from the estimated maximum safety stock level (q_{MAX}) by an incremental amount (e.g., a unit amount) (step 42). The expected amount of safety stock that would have to be supplied from spot market sources to meet expected unmet demand above the reduced safety stock level (q_{SAFETY}) and within the target service level is estimated (step 44). For a given reduced safety stock level (q_{SAFETY}), the expected quantity actually needed from the spot market ($q_{SPOT, ACTUAL}$) to cover target service level requirements over the exposure period may be estimated by the following equation:

$$q_{SPOT, ACTUAL} = \sum_i P(i - 1 < \text{Demand} \leq i) \cdot (i - (\mu_{EXP} + q_{SAFETY}))$$

for $i = \mu_{EXP} + q_{SAFETY} + 1$ to $\mu_{EXP} + q_{MAX}$ (2)

Where $P(x)$ is the probability density function of demand over the exposure period with a mean of μ_{EXP} and a standard deviation of σ_{EXP} . These parameters may be estimated as follows:

$$\mu_{EXP} = \mu_D \cdot (\mu_L + R) \quad (3)$$

$$\sigma_{EXP} = [\mu_D^2 \cdot \sigma_L^2 + (\mu_L + R) \cdot \sigma_D^2]^{1/2} \quad (4)$$

Next, the total expected product costs of the estimated safety stock level
 5 $(C_{SAFETY}(q_{SPOT}))$ and the estimated spot market level $(C_{SPOT}(q_{SPOT}))$ are estimated from the
 reduced safety stock level $(q_{SAFETY} = q_{MAX} - q_{SPOT})$ and the actual spot market level
 $(q_{SPOT, ACTUAL})$ as follows (step 46):

$$C_{SAFETY}(q_{SPOT}) = \rho_{SAFETY} \cdot I_{SAFETY} \cdot (q_{MAX} - q_{SPOT}) \quad (5)$$

$$10 \quad C_{SPOT}(q_{SPOT}) = (\rho_{SPOT} - \rho_{SAFETY}) \cdot q_{SPOT, ACTUAL} \cdot (\# \text{ review periods per year}) \quad (6)$$

Where ρ_{SAFETY} and ρ_{SPOT} are the per-unit costs for products supplied from non-spot
 market sources and spot market sources, respectively, and I_{SAFETY} is the annual
 inventory-driven cost percentage. The per unit spot market cost (ρ_{SPOT}) may
 15 incorporate spot market fees and other costs associated with obtaining products from
 spot market sources.

The total expected product cost $(C_{TOTAL}(q_{SPOT}) = C_{SAFETY}(q_{SPOT}) + C_{SPOT}(q_{SPOT}))$ is
 calculated for each possible value of q_{SPOT} (from 0 to q_{MAX}) (step 48). The optimal
 safety stock level $(q_{SAFETY, OPTIMAL})$ is then determined from the value of q_{SPOT} that results
 20 in the minimum total expected product cost $(C_{TOTAL}(q_{SPOT, OPTIMAL}))$ and
 $q_{SAFETY, OPTIMAL} = q_{MAX} - q_{SPOT, OPTIMAL}$ (step 50). Note that certain simplifying assumptions
 may be made so that $q_{SPOT, OPTIMAL}$ may be computed directly from a closed form
 equation, in which case the iterative loop in the process of FIG. 6 may be avoided.

Referring to FIG. 7, the above-described inventory planning process may be
 25 extended by treating one or more input parameters (e.g., demand, lead time, spot
 market cost or non-spot market cost) stochastically. In accordance with another
 inventory planning embodiment, one or more input parameters are defined as
 random variables (step 52). A set of random samples for each random variable is
 generated (step 54). The sets of random samples may be generated based upon a
 30 selected probability distribution that matches an estimate of the mean and standard
 deviation for the random variable. Random samples are generated from the selected

probability distribution using any one or several conventional techniques (e.g., the inverse transform method). Simulations (e.g., Monte Carlo simulations) are then run over the random variables (step 56). For information relating to Monte Carlo simulation techniques see, for example, PAUL BRATLEY ET AL., A GUIDE TO SIMULATION (1987) and JERRY BANKS ET AL., DISCRETE-EVENT SYSTEM SIMULATION (1996). The resulting data produced from the simulations is collected and analyzed statistically (step 58). This inventory planning process embodiment enables asset managers to make statistically significant decisions relating to one or more of the input parameters and, therefore, make better use of spot markets.

As shown in FIG. 8, in another embodiment, the above-described inventory planning processes may be incorporated into an enterprise resource planning system 60 that is configured to estimate future on-hand inventory requirements and future replenishment requirements. Enterprise resource planning system 60 includes an inventory planning engine 62, a forecast engine 64, an enterprise resource planning engine 66, and a database 68. Inventory planning engine 62 is configured to implement the inventory process of FIG. 6 based upon parameters supplied by a user or by forecast engine 64, or both. Forecast engine 64 is configured to analyze historical shipment data contained in database 68 and to compute an estimate of mean future demand 20 by end customers 12 for products 24, as well as compute an estimate of future demand variability. Forecast engine 64 also may be configured to compute an estimate of mean lead time for ordered products 30 to be received at warehouse 16, as well as compute an estimate of lead time variability. Enterprise resource planning engine 66 is configured to receive inventory planning information from inventory planning engine 62 and forecast information from forecast engine 64, and from this information to estimate inventory levels at various distribution points in the supply chain using standard enterprise resource planning techniques. In particular, enterprise resource planning engine 66 may be operable to recursively compute replenishment requirements for a specific product at each distribution point. The distribution points may include warehouses, terminals or consignment stock at a distributor or a customer. Enterprise resource planning engine 66 may be configured to compute and set re-stock trigger points so that product may be shipped

in time from the manufacturing facility to the distribution points. In one embodiment, enterprise resource planning engine 66 estimates distribution point inventory levels based upon information relating to the lead time needed to manufacture and transport product from the manufacturing facility to the distribution point. Information generated by enterprise resource planning system 60 may be transmitted to a financial planning unit 70, a purchasing unit 72 and a receiving unit 74 to carry out the resource planning recommendations of the system.

III. SPOT MARKET-BASED INVENTORY PLANNING

An asset manager may utilize the above-described inventory planning process to cover uncertainty in future end customer demand with a safety stock level that is less than the safety stock level required to cover expected demand with a desired service level when supply is available only from non-spot market sources. In this way, an asset manager may trade some certainty in product price for shorter and more certain product delivery times to reduce overall product costs by reducing the level of safety stock kept on hand. After the optimal (reduced) safety stock level ($q_{\text{SAFETY, OPTIMAL}}$) has been ordered and is on hand, the enterprise will meet demand from inventory until the safety stock level has been depleted, at which point the enterprise will meet demand with supplies purchased on the spot market.

Referring to FIG. 9, in one embodiment, an asset manager may plan a safety stock level to cover uncertainty in demand over an exposure period with a desired service level based at least in part upon product availability from a spot market as follows. The asset manager first computes estimates of various inventory planning parameters, including an estimate of mean demand, an estimate of demand uncertainty, an estimate of mean lead time, and an estimate of lead time uncertainty (step 80). Various forecasting techniques may be used to project the future product demand parameters and the future delivery lead time parameters. For example, these parameters may be estimated based upon a variety of information, such as experience, customer information, non-spot market supplier information, and general economic conditions. Alternatively, these parameters may be forecasted based upon an analysis of historical shipment data using known statistical techniques. Next, the asset manager selects a desired service level (step 82). The selected service level

establish a product spot market (or auction) Web site that enables one or more product suppliers 104 to attract numerous buyers 106 who, as a group, will determine a final price for the products being auctioned. In addition, server computer 100 may be configured to provide information that would enable buyers 106 to make better use of the spot market (e.g., information that would enable asset managers to plan inventory levels when supply is available from the spot market). The spot market established by server computer 100 may be structured to enable sellers 104 to select the products to be sold and the times at which the products will be offered for sale. Sellers 104 also may be permitted to specify a minimum price below which the product may not be sold; alternatively, sellers 104 may be permitted to reject the established market price for an item, unless the item is being sold without reserve.

In one embodiment, server 100 is accessible by buyers 106 and sellers 104 over the Internet. The Internet includes a vast number of computers and computer networks that are interconnected through communication links. The interconnected computers exchange information using various services (e.g., electronic mail, Gopher, and the World Wide Web ("WWW")). The WWW service allows server computer 100 (i.e., Web server or Web site) to send graphical Web pages of information to buyer client computers 106 and to seller client computers 106. The remote client computers may then display the Web pages. Each resource (e.g., computer or Web page) of the WWW is uniquely identifiable by a Uniform Resource Locator ("URL"). To view a specific Web page, a client computer specifies the URL for that Web page in a request (e.g., a HyperText Transfer Protocol ("HTTP") request). The request is forwarded to the Web server that supports that Web page. When that Web server receives the request, it sends that Web page to the client computer system. When the client computer receives that Web page, it typically displays the Web page using a browser, which is a special-purpose application program that requests and displays Web pages.

Web pages typically are defined using HyperText Markup Language ("HTML"). HTML provides a standard set of tags that define how a Web page is to be displayed. When a user indicates to the browser to display a Web page, the

browser sends a request to the server computer system to transfer to the client computer system an HTML document that defines the Web page. When the requested HTML document is received by the client computer, the browser displays the Web page as defined by the HTML document. The HTML document contains various tags that control the displaying of text, graphics, controls, and other features. The HTML document may contain URLs of other Web pages available on that server computer system or other server computer systems.

Referring to FIG. 11, in one embodiment, server computer 100 includes a processing unit 114, a system memory 116, and a system bus 118 that couples processing unit 114 to the various components of server computer 100. Processing unit 114 may include one or more processors, each of which may be in the form of any one of various commercially available processors. System memory 116 includes a read only memory (ROM) 120 that stores a basic input/output system (BIOS) containing start-up routines for server computer 100, and a random access memory (RAM) 122. System bus 118 may be a memory bus, a peripheral bus or a local bus, and may be compatible with any of a variety of bus protocols, including PCI, VESA, Microchannel, ISA, and EISA.

Server computer 100 also includes a hard drive 124, a floppy drive 126, and CD ROM drive 128 that are connected to system bus 118 by respective interfaces 130, 132, 134. Hard drive 124, floppy drive 126 and CD ROM drive 128 contain respective computer-readable media disks 136, 138, 140 that provide non-volatile storage for data, data structures and computer-executable instructions (e.g., instructions implementing inventory planning engine 62). Other computer-readable storage devices (e.g., magnetic tape drives, flash memory devices, and digital video disks) also may be used with server computer 100. A user may interact (e.g., enter commands or data) with server computer 100 using a keyboard 142 and a mouse 144. Other input devices (e.g., a microphone, joystick, or touch pad) also may be provided. Information may be displayed to the user on a monitor 146. Server computer 100 also may include peripheral output devices, such as speakers and a printer.

Remote seller client computers 104, remote buyer client computers 106, and other remote computers 150, which are accessible over a local area network (LAN) 152, may be workstations, server computers, routers, peer devices or other common network nodes.

5 Referring to FIGS. 12 and 13, in one embodiment, server computer 100 may be configured to provide inventory planning services to buyers 106 as follows. When a buyer 106 initially accesses the spot market Web site established by server computer 100, server computer 100 generates a login window (or Web page) through which the buyer must pass before being allowed to navigate to other parts of the spot
10 market Web site (step 160). The login window may prompt the buyer to enter a user name and a password if the buyer currently is registered with the spot market, or the login window may prompt the user to register with the spot market. After the buyer successfully enters the user name and password of a registered user, server 100 generates an inventory planning window 162 that will provide to the user
15 information relating to use of the spot market to plan inventory levels (step 164). Within the inventory planning window (162), server computer generates an input parameter section 166 (step 168) and an analysis section 170 (step 172).

Input parameter section 166 prompts the buyer to enter data relating to inventory holding costs 174, product demand characteristics 176 (e.g., estimates of
20 mean demand and demand uncertainty), product delivery characteristics 178 (e.g., estimates of mean lead time and lead time uncertainty), the target service level 180, and spot market costs 182 (e.g., per unit product cost and other spot market fees relating to obtaining products from the spot market). The buyer may enter estimates for each of the input parameters, or the buyer may upload historical data stored on a
25 database 184 (see FIG. 10) from which server 100 may compute estimates for each of the input parameters. Server computer 100 preferably includes one or more computer application programs that are operable to implement known statistical techniques for computing estimates of each of the input parameters from historical data. In some embodiments, a communication link (e.g., a hyperlink to a remote
30 computer address) may be provided enabling question-and-answer communication between a client computer and a remote computer. The remote computer may be

networked with LAN 152 (FIG. 11), and may be configured to provide information relating to the estimation of one or more of the input parameters. The information may be provided passively (e.g., textual descriptions of one or more statistical approaches that may be used to compute one or more of the input parameters), or
5 dynamically (e.g., a macro or Wizard based routine that guides users through the computation process). Alternatively, a user may communicate with a customer service expert qualified to answer questions relating to use of the system or relating to the estimation of the input parameters. The user may communicate with the customer service expert by e-mail or over the phone.

10 After estimates for each of the input parameters have been obtained, server computer 100 uses inventory planning engine 62 to compute estimates of the expected safety stock cost, the expected spot market cost, and total expected cost as a function of expected unmet demand within the target service level requirements to be satisfied by products obtained from the spot market (step 186). Server computer
15 100 graphically displays the computed cost estimates in analysis section 170 (step 188). In addition, server computer 100 computes the minimum total cost (step 190), and displays in analysis section 170 the optimal level of expected unmet demand to be satisfied by the spot market ($q_{\text{SPOT, OPTIMAL}}$) (step 192). Server 100 preferably also displays the optimal level of safety stock ($q_{\text{SAFETY, OPTIMAL}}$) to be kept on hand to
20 minimize the total expected cost.

Referring back to FIG. 10, server computer 100 also may be configured to store various kinds of information in a database 194. For example, in addition to storing information relating to registered buyers and sellers, server 100 may store historical price data for products auctioned on the spot market. This historical price
25 information may be analyzed statistically, and the analyzed spot market historical price statistics may be provided to buyers 106 to assist them in their inventory planning decision-making.

Other embodiments are within the scope of the claims.

The systems and methods described herein are not limited to any particular
30 hardware or software configuration, but rather they may be implemented in any computing or processing environment. The inventory planning engine preferably is

implemented in a high level procedural or object oriented programming language; however, the program may be implemented in assembly or machine language, if desired. In any case, the programming language may be a compiled or interpreted language.

5 In one embodiment, the inventory planning engine described above was implemented as a Visual Basic® for Applications (VBA) computer program operable as a spreadsheet tool in the Microsoft® Excel application program. The following VBA code computes equations (1)-(4) and (6) above; the remaining computations, including the cost minimization process, may be performed within a Microsoft® Excel
10 spreadsheet using standard cell functions.

' Definition of input arguments

15	' demandMean:	Mean weekly demand (units/week)
	' demandSD:	Standard deviation of weekly forecast error (units/week)
	' replenishmentTimeMean:	Mean replenishment time--order to receipt (weeks)
	' replenishmentTimeSD:	Standard deviation of replenishment time (weeks)
20	' reviewPeriod:	Review period--for reviewing inventory status (weeks)
	' deliveryFrequency:	Replenishment frequency (receipts/week)
	' * availabilityRate:	Customer service level--fill rate (fraction)
	' * inventoryOnhandWeeks:	Average on-hand inventory (weeks of supply)
25	' promisedDeliveryTime:	Promised delivery time--SRT--less production time (weeks)

' Definition of output parameters

30	' inventorySafetyUnits:	Safety stock (units)
	' inventoryOnhandUnits:	Average on-hand inventory (units)
	' * inventoryOnhandWeeks:	Average on-hand inventory (weeks of supply)
	' * availabilityRate:	Customer service level or fill rate (fraction)
	' delayTimeWeeks:	Mean delay time when a stockout occurs (weeks)
35	' inventoryPositionUnits:	Target stock level, order-up-to point (units)

40 ' Calculates INVENTORY levels, based on customer service, using the BTO model
Function calcInventoryBTO(demandMean As Double, _

DemandSD As Double, _
 replenishmentTimeMean As Double, _
 replenishmentTimeSD As Double, _
 ReviewPeriod As Double, _
 5 deliveryFrequency As Double, _
 availabilityRate As Double, _
 promisedDeliveryTime As Double)

Dim inventoryResultsBTO(5) As Double

Dim inventorySafetyUnits As Double
 Dim inventoryOnhandUnits As Double
 Dim inventoryOnhandWeeks As Double
 Dim delayTimeAverage As Double
 15 Dim inventoryPositionUnits As Double
 Dim inventoryCycleUnits As Double
 Dim demandReplMean As Double
 Dim demandReplSD As Double

20 ' Calculate cycle stock (units)
 inventoryCycleUnits = demandMean / (deliveryFrequency * 2)

inventorySafetyUnits = SafetyStock(demandMean, _
 DemandSD, _
 25 replenishmentTimeMean, _
 replenishmentTimeSD, _
 ReviewPeriod, _
 (1 - availabilityRate), _
 promisedDeliveryTime)

30 ' Calculate average on-hand inventory (units)
 inventoryOnhandUnits = inventorySafetyUnits + inventoryCycleUnits

35 ' Calculate average on-hand inventory (weeks)
 inventoryOnhandWeeks = inventoryOnhandUnits / demandMean

' Calculate the mean delay time
 delayTimeAverage = delayWeeksMean(demandMean, _
 DemandSD, _
 40 replenishmentTimeMean, _
 replenishmentTimeSD, _
 ReviewPeriod, _
 inventorySafetyUnits)

45 ' Calculate the inventory position (units)
 inventoryPositionUnits = inventorySafetyUnits + demandReplMean

```

' Gather the results together in an array
inventoryResultsBTO(1) = inventorySafetyUnits
inventoryResultsBTO(2) = inventoryOnhandUnits
5 inventoryResultsBTO(3) = inventoryOnhandWeeks
inventoryResultsBTO(4) = delayTimeAverage
inventoryResultsBTO(5) = inventoryPositionUnits

```

```

' Return the array of results
10 calcInventoryBTO = inventoryResultsBTO

```

End Function

```

15 ' Calculates stockout rate at a point in time
Function delayWeeksMean(demandMean As Double, _
                        DemandSD As Double, _
                        replenishmentTimeMean As Double, _
20 replenishmentTimeSD As Double, _
                        ReviewPeriod As Double, _
                        inventorySafetyUnits As Double)
    Dim incStockout As Double
    Dim sumStockout As Double
25 Dim tempTime As Double
    Dim numPeriods As Long
    Dim timePeriod As Long

    ' Calculate the maximum number of iterations
30 numPeriods = Int(demandReplVar(demandMean, _
                                DemandSD, _
                                replenishmentTimeMean, _
                                replenishmentTimeSD, _
                                ReviewPeriod, _
35 0) / DemandSD ^ 2)

    ' Initialize the loop variables
    timePeriod = 0
    sumStockout = 0
40

    ' Loop over the time periods calculating the probability of a stockout;
    ' Stop when incremental change is too small to worry about

Do
45    tempTime = timePeriod

```

```

incStockout = stockoutRate(demandMean, _
                           DemandSD, _
                           replenishmentTimeMean, _
                           replenishmentTimeSD, _
5                           ReviewPeriod, _
                           inventorySafetyUnits, _
                           tempTime)
sumStockout = sumStockout + incStockout
timePeriod = timePeriod + 1
10
Loop While (timePeriod < numPeriods And _
           incStockout >= (0.001 * sumStockout))

15 ' Calculate mean delay time
delayWeeksMean = (sumStockout / stockoutRate(demandMean, _
                                              DemandSD, _
                                              replenishmentTimeMean, _
                                              replenishmentTimeSD, _
20                                              ReviewPeriod, _
                                              inventorySafetyUnits, _
                                              0) - 0.5) * ReviewPeriod

```

End Function

```

' Calculates units of safety stock commensurate with a
' probability of stocking out at a point in time
30 Function SafetyStock(demandMean As Double, _
                      DemandSD As Double, _
                      replenishmentTimeMean As Double, _
                      replenishmentTimeSD As Double, _
                      ReviewPeriod As Double, _
                      stockoutRate As Double, _
35                      timeShift As Double)

Dim demandReplSD As Double
Dim safetyStockFactor As Double
40
' Calculate SD of replenishment (pipeline) demand
demandReplSD = Sqr(demandReplVar(demandMean, _
                                DemandSD, _
                                replenishmentTimeMean, _
                                replenishmentTimeSD, _
45                                ReviewPeriod, _

```

timeShift))

' Calculate safety stock factor

safetyStockFactor = -Application.NormSInv(stockoutRate)

' Calculate safety stock (units)

SafetyStock = (safetyStockFactor * demandReplSD) - (demandMean * timeShift)

End Function

' Calculates probability of a stockout at a point in time

Function stockoutRate(demandMean As Double, _

DemandSD As Double, _

replenishmentTimeMean As Double, _

replenishmentTimeSD As Double, _

ReviewPeriod As Double, _

inventorySafetyUnits As Double, _

timeShift As Double)

Dim demandReplSD As Double

Dim safetyStockFactor As Double

' Calculate SD of replenishment (pipeline) demand

demandReplSD = Sqr(demandReplVar(demandMean, _

DemandSD, _

replenishmentTimeMean, _

replenishmentTimeSD, _

ReviewPeriod, _

timeShift))

' Calculate safety stock factor

safetyStockFactor = (inventorySafetyUnits + (demandMean * timeShift)) /
demandReplSD

' Calculate stockout rate (fraction)

stockoutRate = Application.NormSDist(-safetyStockFactor)

End Function

' Calculates uncertainty of replenishment (pipeline) demand (as a variance)

Function demandReplVar(demandMean As Double, _

DemandSD As Double, _

```
replenishmentTimeMean As Double, _
replenishmentTimeSD As Double, _
ReviewPeriod As Double, _
timeShift As Double)
```

5

Dim adjReplTime As Double

```

' Adjust the replenishment time, but keep the result positive
adjReplTime = replenishmentTimeMean + ReviewPeriod - timeShift

```

10

```

If (adjReplTime < 0) Then
    adjReplTime = 0
End If

```

15

```
' Calculate the variance of replenishment (pipeline) demand
demandReplVar      = (demandMean ^ 2 * replenishmentTimeSD ^ 2) +
                    (DemandSD ^ 2 * adjReplTime)
```

End Function

20

'Calculate the expected Auction Cost

25

```
Function ExpAuCost(SafetyStock As Single, _
    AuctionVolume As Single, _
    MeanDemand As Single, _
    DemandCoV, _
    MeanLeadTime As Single, _
    LeadTimeCoV As Single, _
    ReviewPeriod As Single, _
    AuctionCost As Single, _
    TraditionalCost As Single)
```

35

```
Dim x As Integer
Dim prb As Single
Dim ReducedSS As Single
Dim E As Single
Dim LeadTimeSD As Single
Dim DemandSD As Single
Dim PriceDelta As Single
Dim ExposureMean As Single
Dim ExposureSD As Single
Const WeeksInYear = 52
```

45

$$\text{ReducedSS} = \text{SafetyStock} - \text{AuctionVolume}$$

'Demand and Lead Time Standard Deviation

DemandSD = MeanDemand * DemandCoV

LeadTimeSD = MeanLeadTime * LeadTimeCoV

5

' Calculation of the mean and standard deviation of demand over the exposure period

ExposureMean = MeanDemand * (MeanLeadTime + ReviewPeriod)

10 ExposureSD = Sqr(MeanDemand ^ 2 * LeadTimeSD ^ 2 + (MeanLeadTime + ReviewPeriod) * DemandSD ^ 2)

'Difference in product price between auction and traditional channel

PriceDelta = AuctionCost - TraditionalCost

15

'Numerical calculation of the expected value by which the demand in the exposure period will exceed the Reduced Safety Stock (up to the full Safety Stock);
'this is the expected amount that must be purchased from the auction

20 For x = ReducedSS + 1 To SafetyStock

prb = Application.NormDist(ExposureMean + x, ExposureMean, ExposureSD, 1) - Application.NormDist(ExposureMean + x - 1, ExposureMean, ExposureSD, 1)

25

ExpAuCost = ExpAuCost + prb * (x - ReducedSS) * PriceDelta

Next x

30 'annualize the result

ExpAuCost = ExpAuCost * (WeeksInYear / ReviewPeriod)

End Function

35

Still other embodiments are within the scope of the claims.